Improvements in CALIPSO Version 3 and New Products

Dave Winker

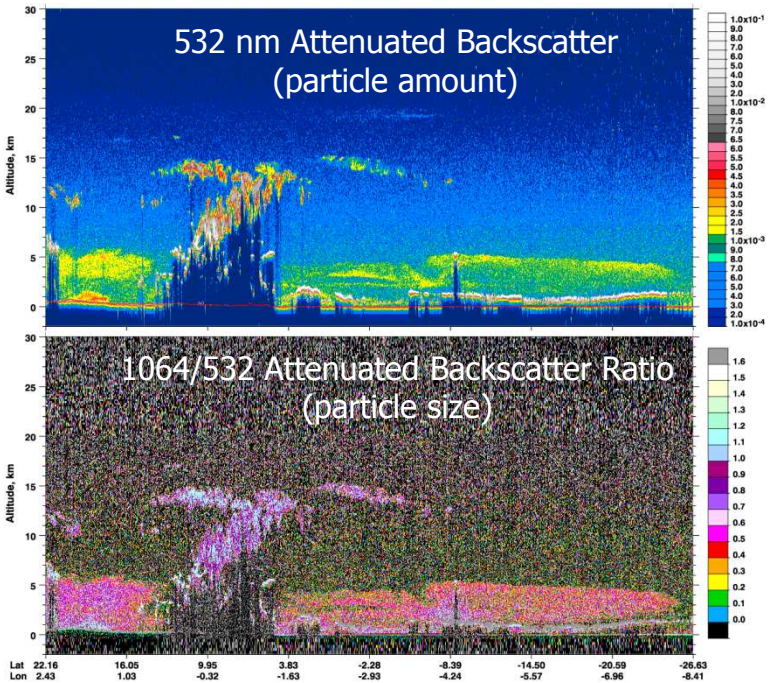
and Mark Vaughan, Ali Omar, Zhaoyan Liu, Yongxiang Hu, Brian Getzewich, and Jason Tackett

CERES/GERB Mtg, Paris, Sept 2010

Version 3 Highlights

Version 2
3-D CAD
(no depol!)

Altitude +

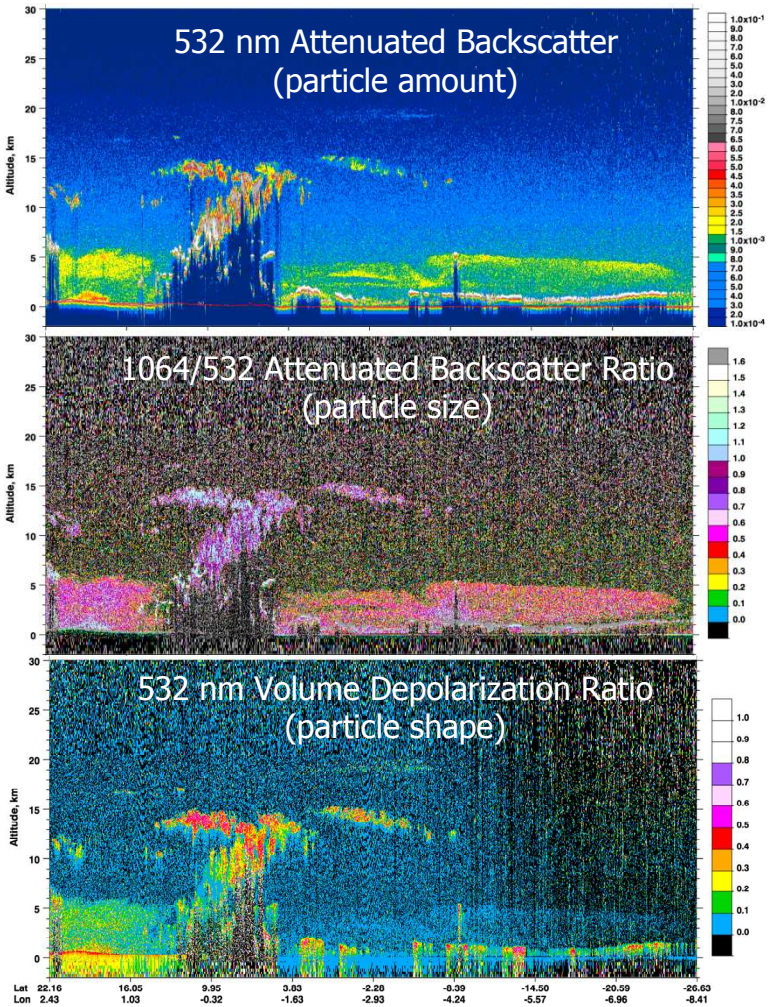


New CAD algorithm
3D → 5D Classification

Version 3
5-D CAD

Altitude +

Latitude +

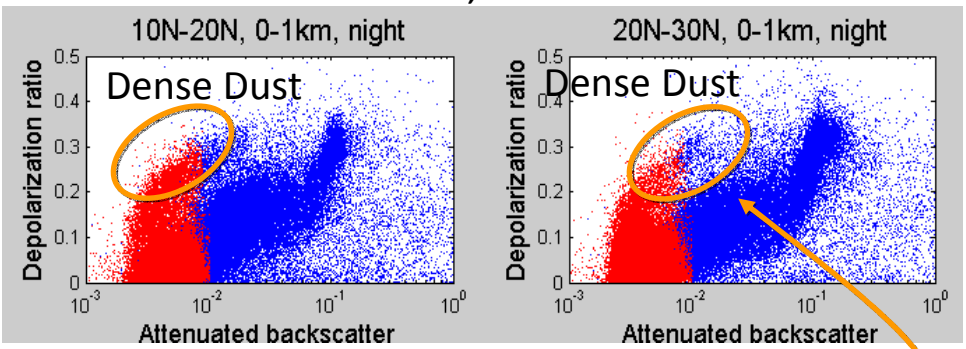


Liu et al., The CALIPSO Cloud and Aerosol Discrimination: Version 3 Algorithm and Test Results, ILRC 25

New CAD algorithm
3D → 5D Classification

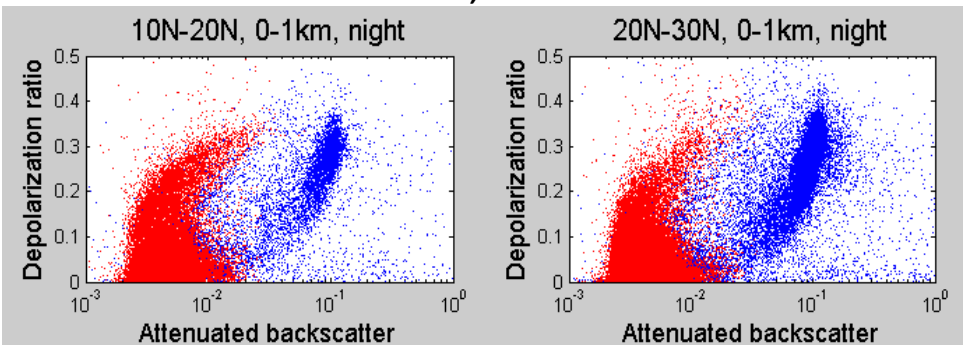
Separation between cloud and aerosol & dust classification improved in V3

3D, V2.01



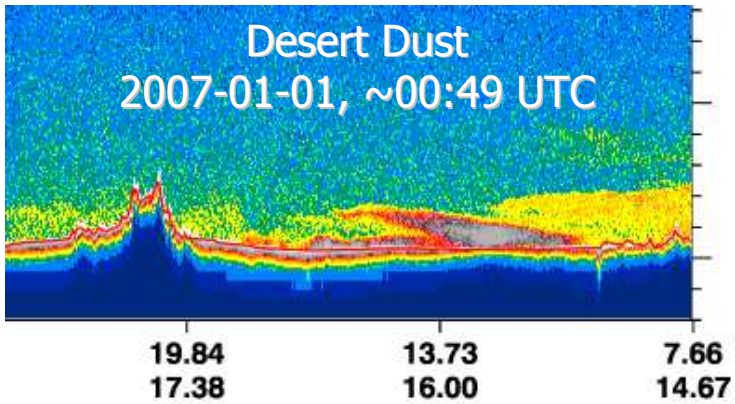
"Continuum" due to cloud-clearing bug

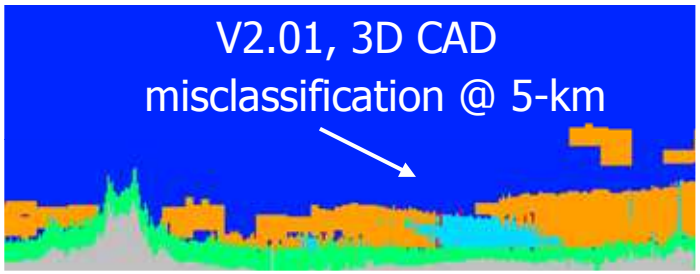
5D, v2.94

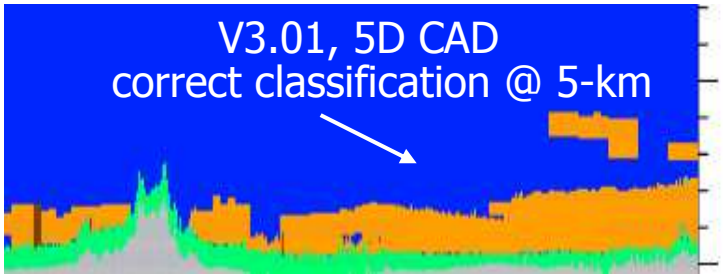


depol →

backscatter →



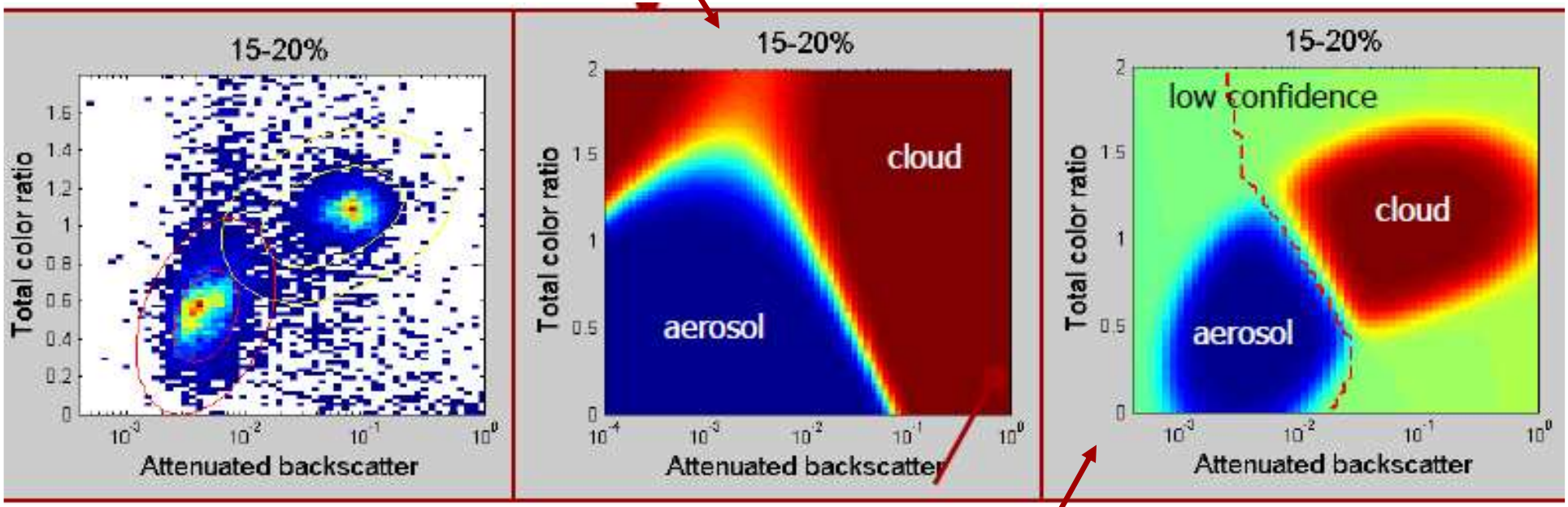




CAD_score logic flaw corrected in V3

Distribution of γ'_{532} and χ' for
- $0.15 < \delta < 0.20$
- $20° \text{ N} < \text{latitude} < 30° \text{ N}$
- $0 \text{ km} < Z_{mid} < 1 \text{ km}$

$$\text{CAD score} = 100\left(\frac{P_{cloud}(layer) - P_{aerosol}(layer)}{P_{cloud}(layer) + P_{aerosol}(layer)}\right)$$



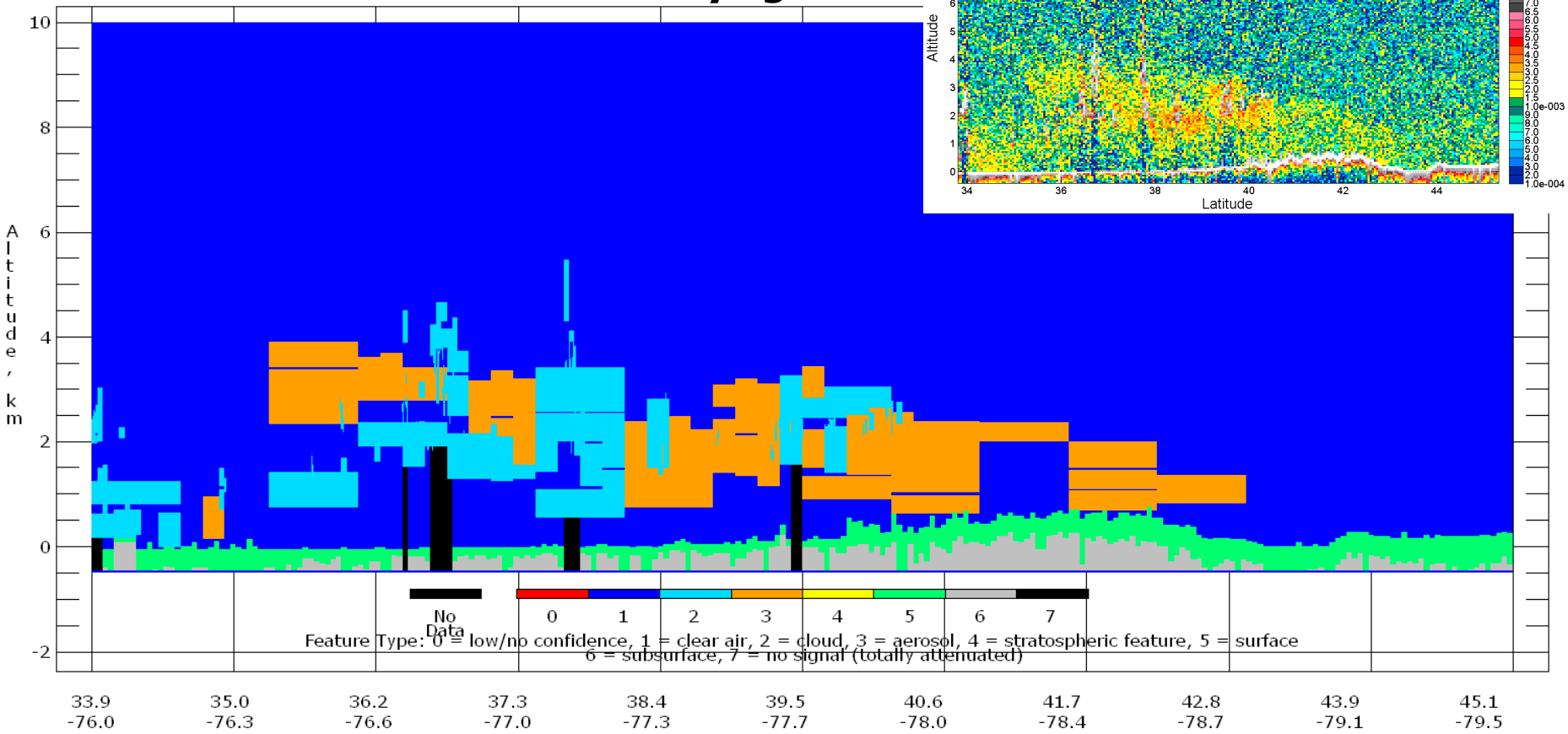
$$\text{CAD score} = 100\left(\frac{\left(P_{cloud}(layer) + \Delta P_{cloud}\right) - \left(P_{aerosol}(layer) + \Delta P_{aerosol}\right)}{\left(P_{cloud}(layer) + \Delta P_{cloud}\right) + \left(P_{aerosol}(layer) + \Delta P_{aerosol}\right)}\right)$$

Two Issues

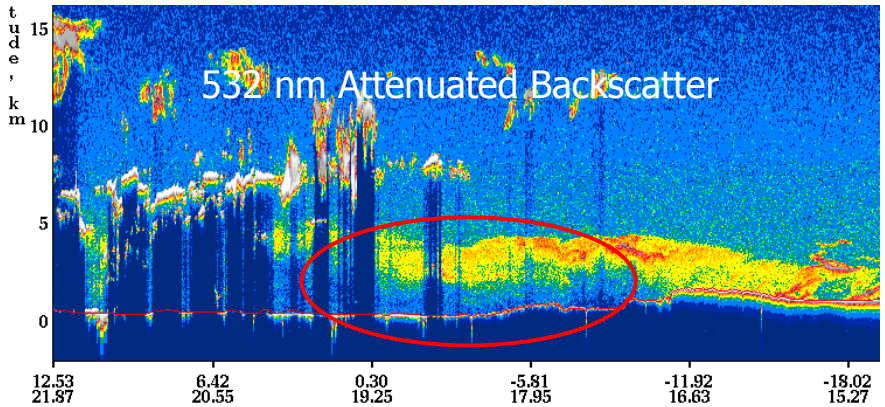
VERSION 2

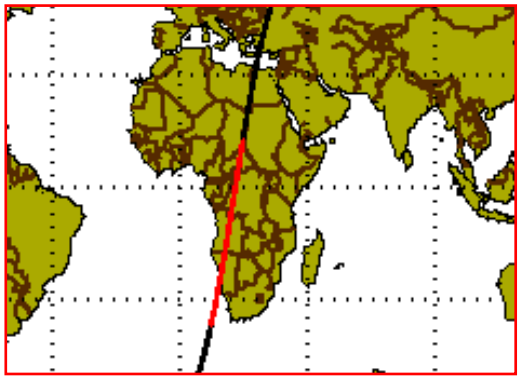
software bug in low-altitude cloud-clearing loop

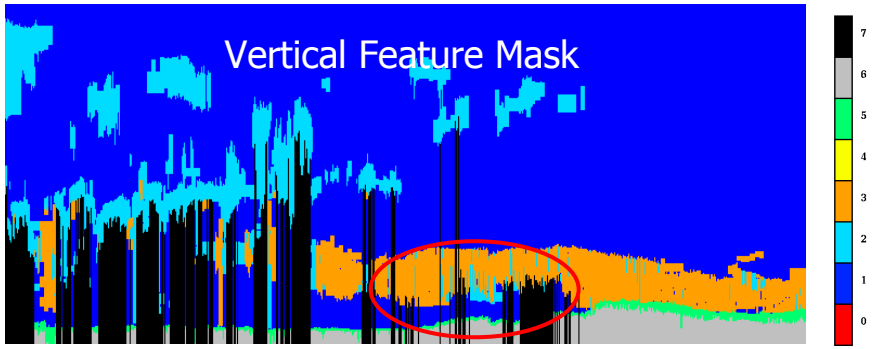
aerosol base detection not always good

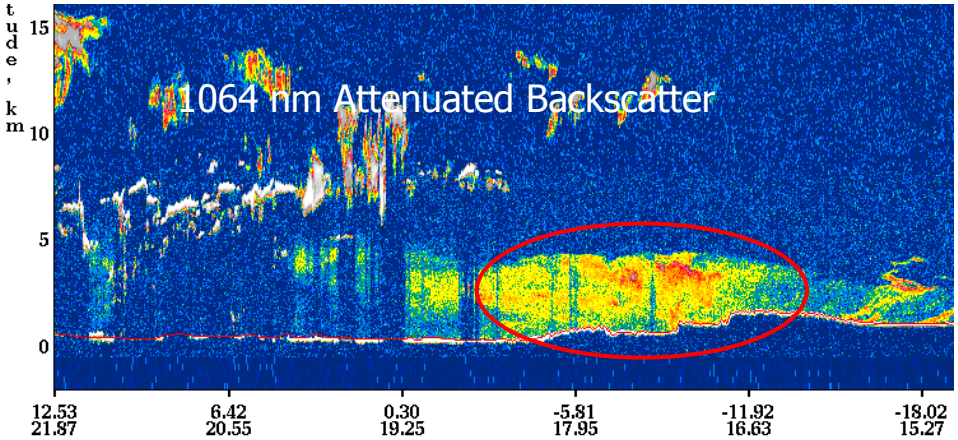


V2 Aerosol base detection sometimes too high



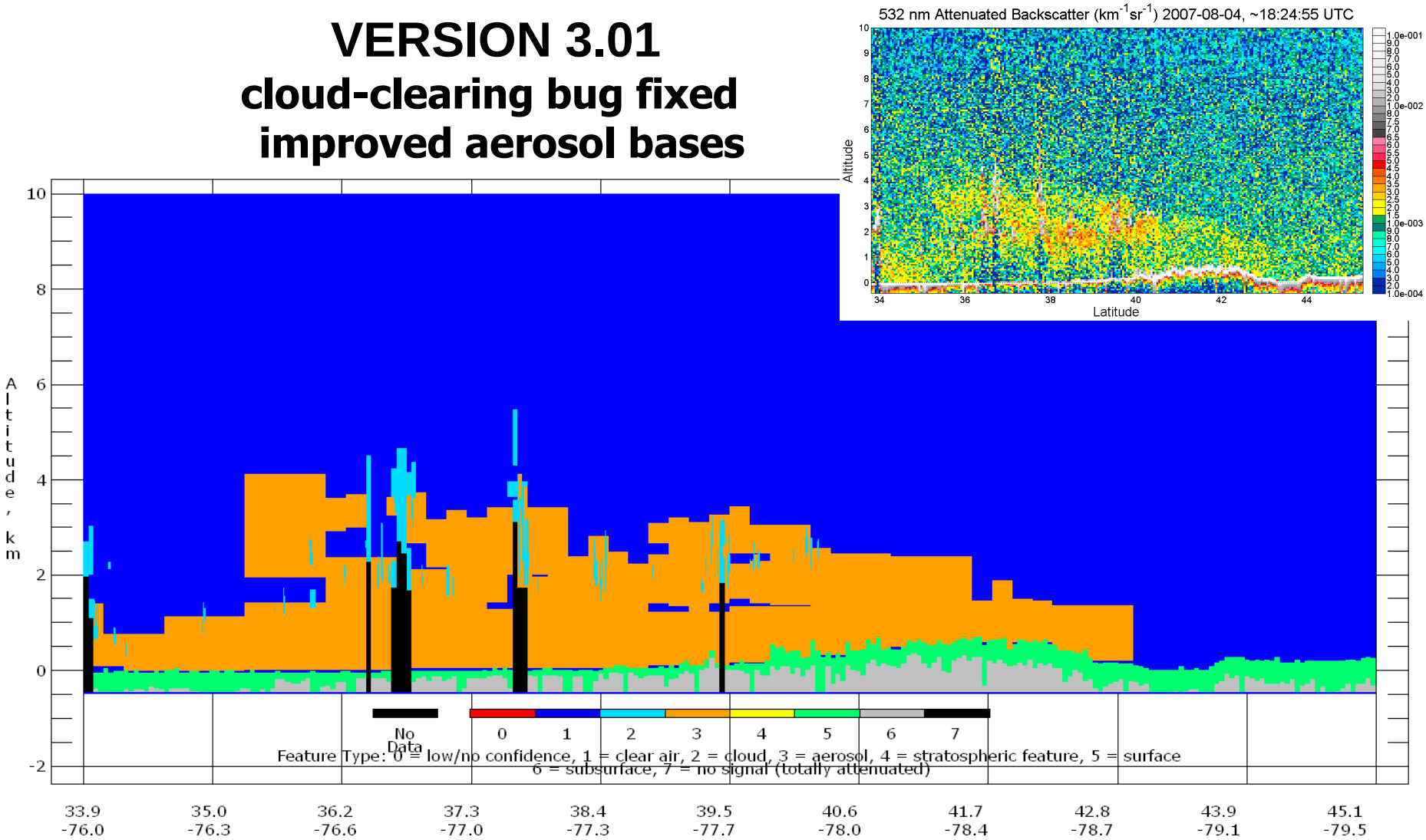




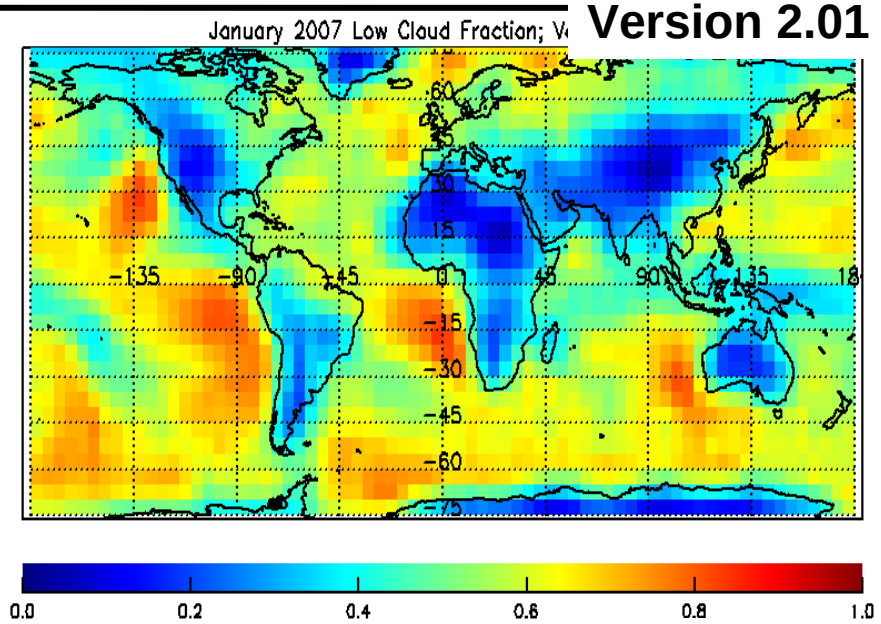


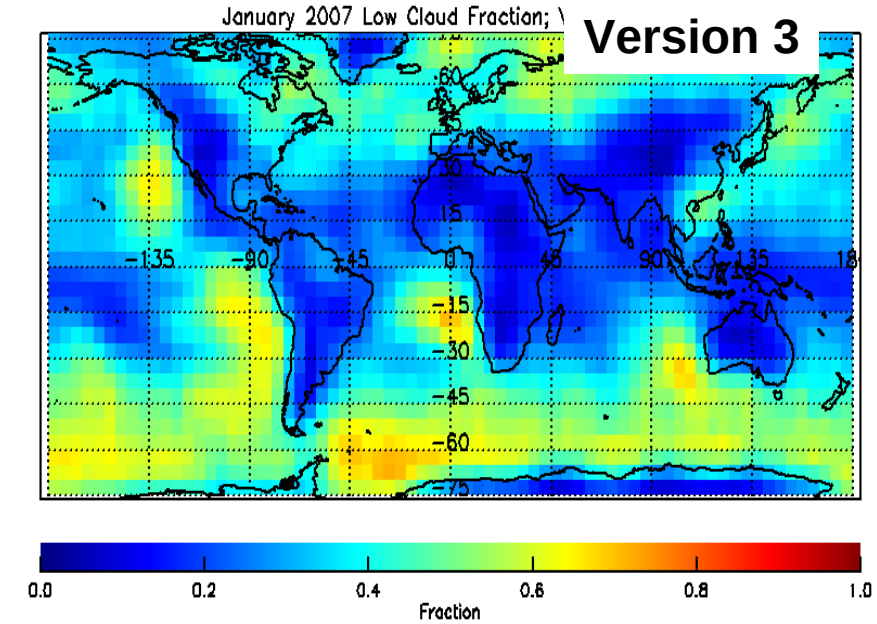
Improved Aerosol Base Detection

VERSION 3.01
cloud-clearing bug fixed
improved aerosol bases



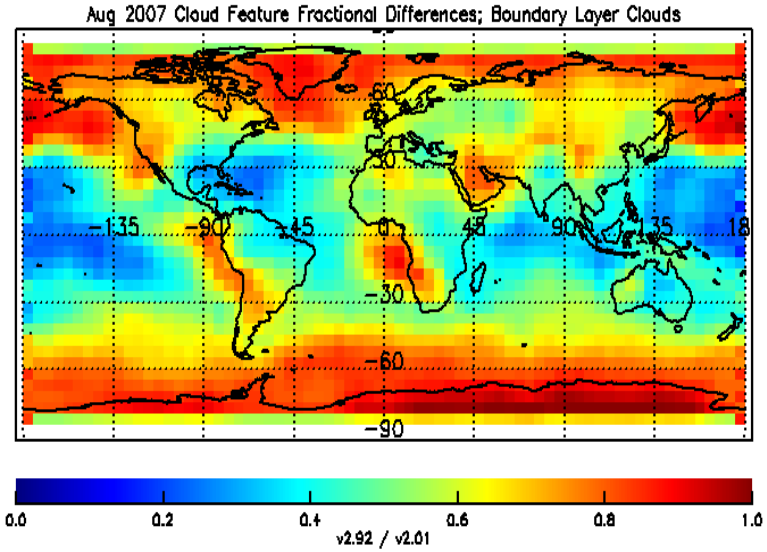
Result: single-layer low clouds





When all 5-km clouds are counted, global mean cover of single-layer low cloud reduced from 26.1% to 21.8% in V3 – but 5-km clouds are optically thin ($\tau << 1$)

Biggest effects in low latitude oceans



ratio of V3 / V2 low cloud

Restructured Profile Products

Version 2:

- Profiles of aerosol and cloud 532 and 1064 extinction and backscatter only
- Aerosol profiles reported at 40 km, clouds at 5 km

Version 3:

Both aerosol and cloud profile products now retrieved at 5-20-80 km and reported at 5-km horizontal resolution

Additional profiles:

- 532 nm perpendicular backscatter and particle depolarization
- Atmospheric Volume Description (cloud/aerosol/clear etc.)
- Cloud fraction
- Backscatter and extinction uncertainties

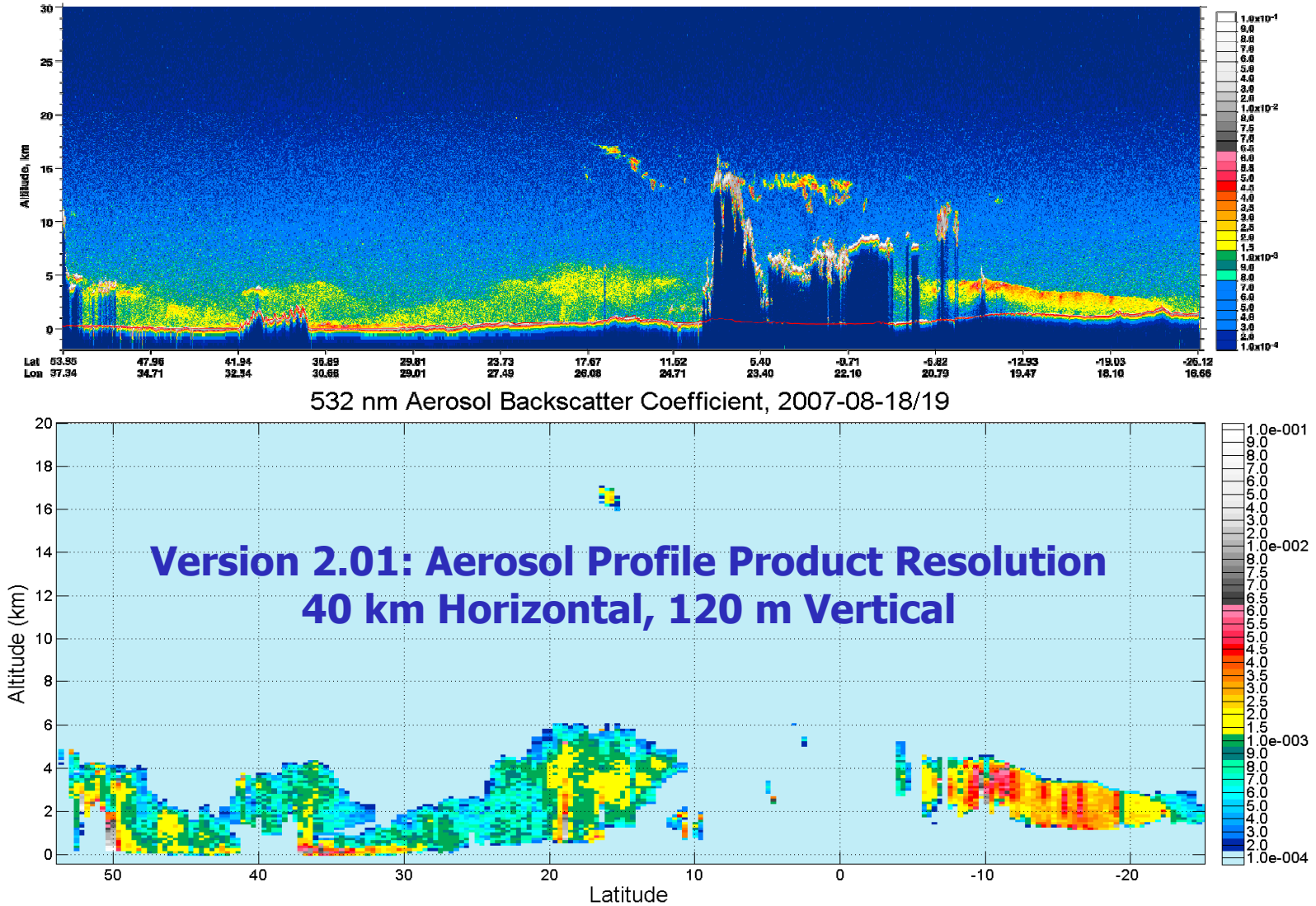
Added column parameters

- Column optical depth: cloud, aerosol, stratosphere
- Column integrated attenuated backscatter (IAB)

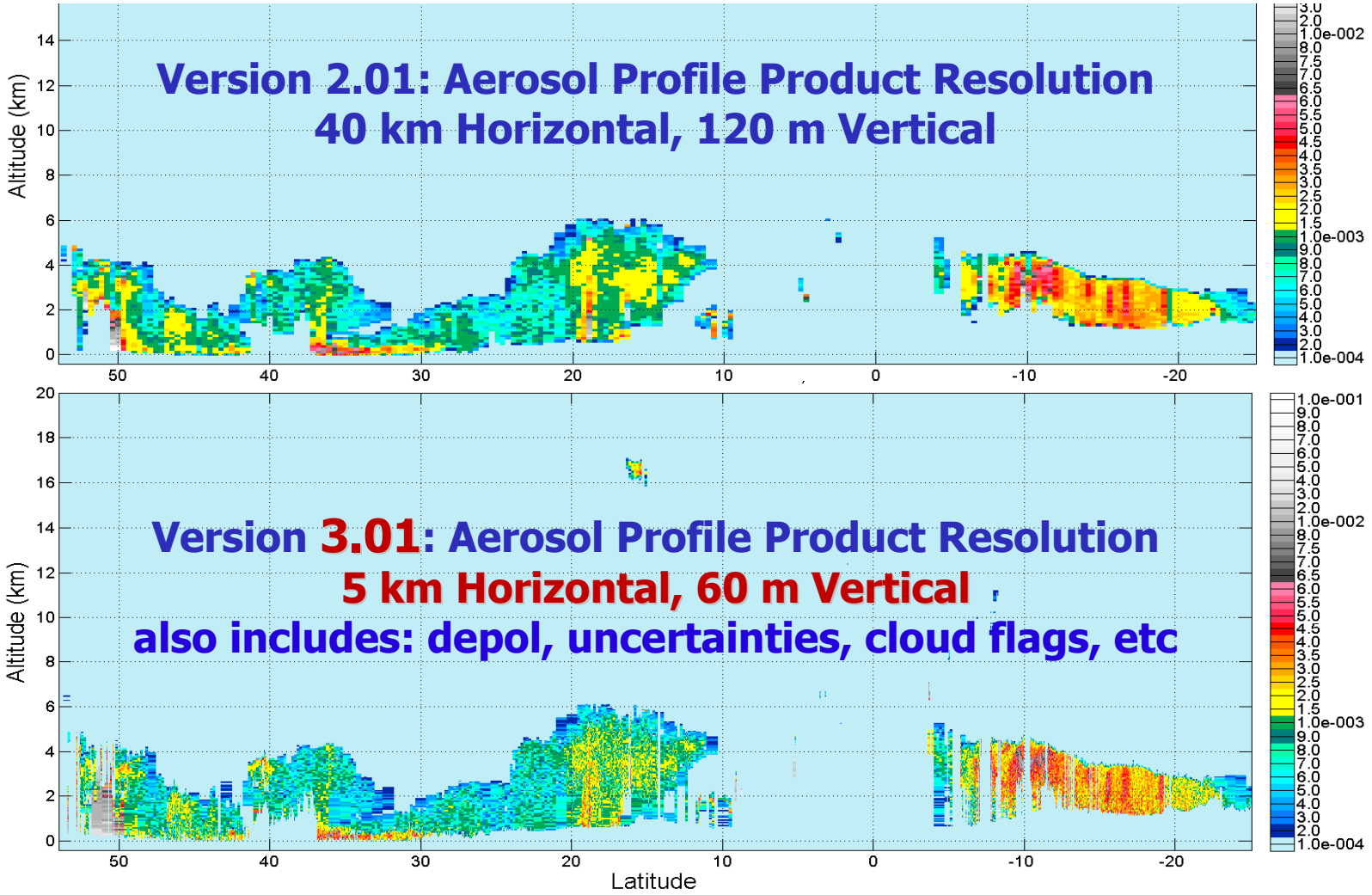
Data quality information

- CAD score, Ext_QC flag, Feature type QA flags

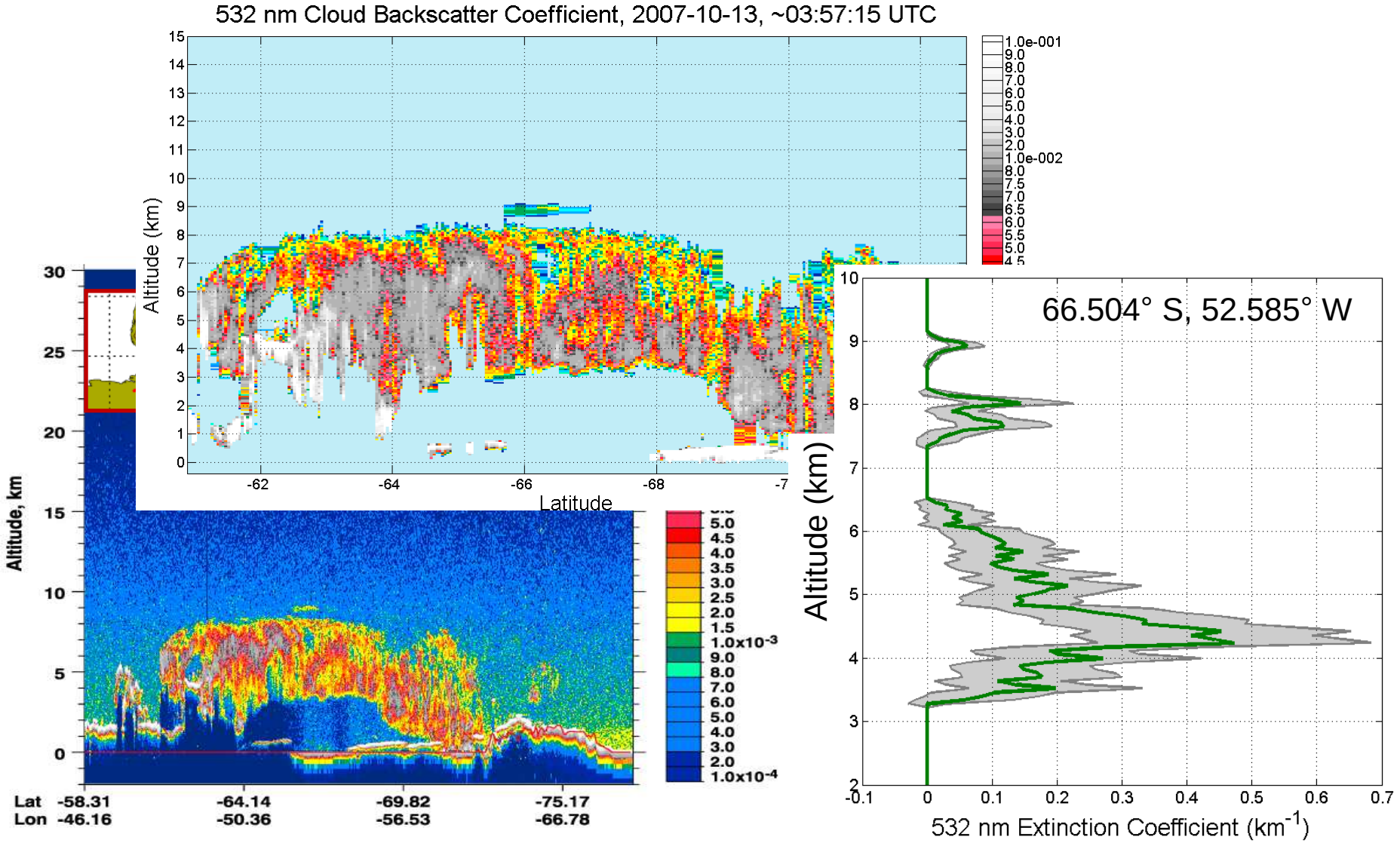
New aerosol profile product



Aerosol profiles now reported at 5-km



Uncertainties now included



Extinction Uncertainty Estimate

Uncertainty in Particulate Backscatter Coefficients at Altitude *n*

$$\frac{\sigma^2(\beta_{p,n})}{\beta_{p,n}^{\ 2}} = A_n^{\ 2}\left(\left(\frac{\sigma^2(X_n)}{X_n^{\ 2}}\right)+\left(\frac{1}{R_n}\right)^2\left(\frac{\sigma^2(\beta_{m,n})}{\beta_{m,n}^{\ 2}}\right)+(2\eta\tau_{p,n})^2\left(\frac{\sigma^2(S)}{S^2}+\frac{\sigma^2(\eta)}{\eta^2}\right)+\left(\frac{\sigma^2(T^2_{p,n-1})}{(T^2_{p,n-1})^2}+B_n^{\ 2}\left(\frac{\sigma^2(\beta_{p,n-1})}{\beta_{p,n-1}^{\ 2}}\right)\right)\right)$$

Measurement Uncertainty

Molecular Number Density Uncertainty

Lidar Ratio Uncertainty

Multiple Scattering Uncertainty

Accumulated Aerosol Attenuation Uncertainty

Includes errors due to

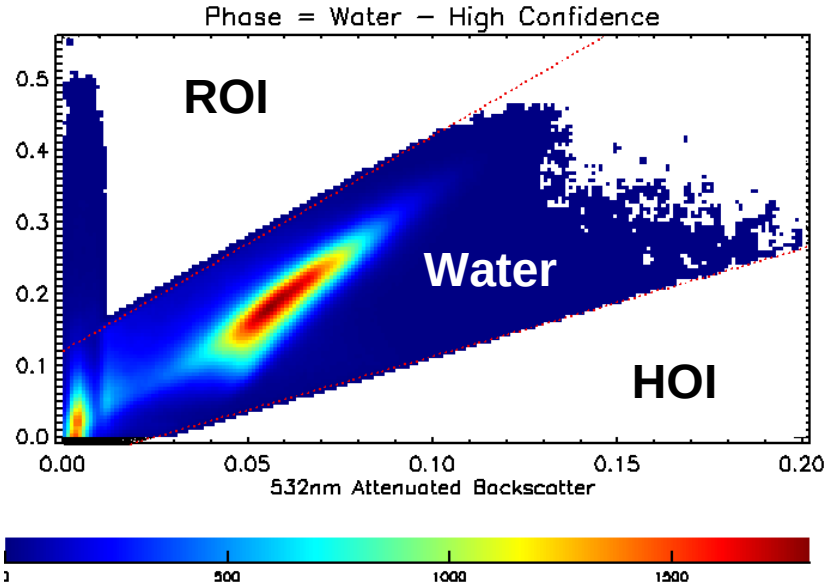
- ⇨ **Calibration**
- ⇨ **SNR**
- ⇨ molecular density (again)
- ⇨ offset calculations
- ⇨ polarization gain ratio
- ⇨ polarization cross-talk
- ⇨ ranging

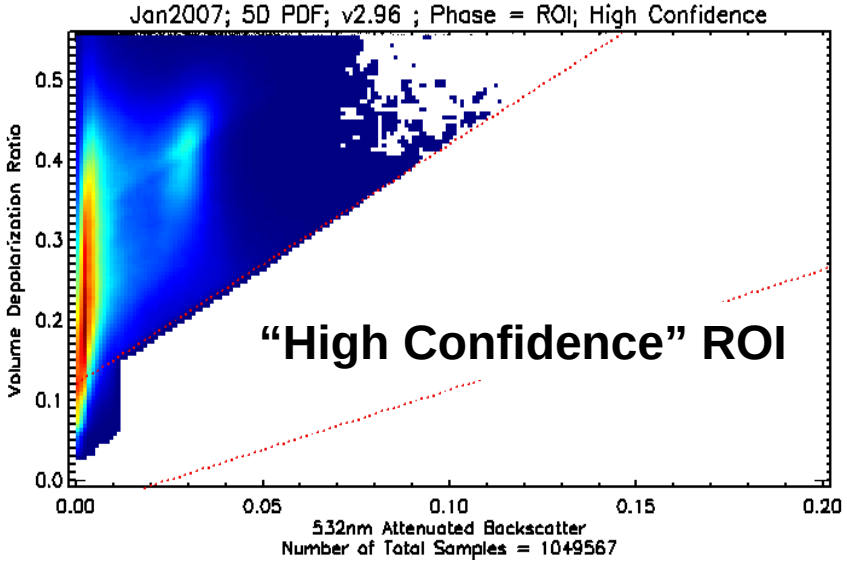
LEGEND

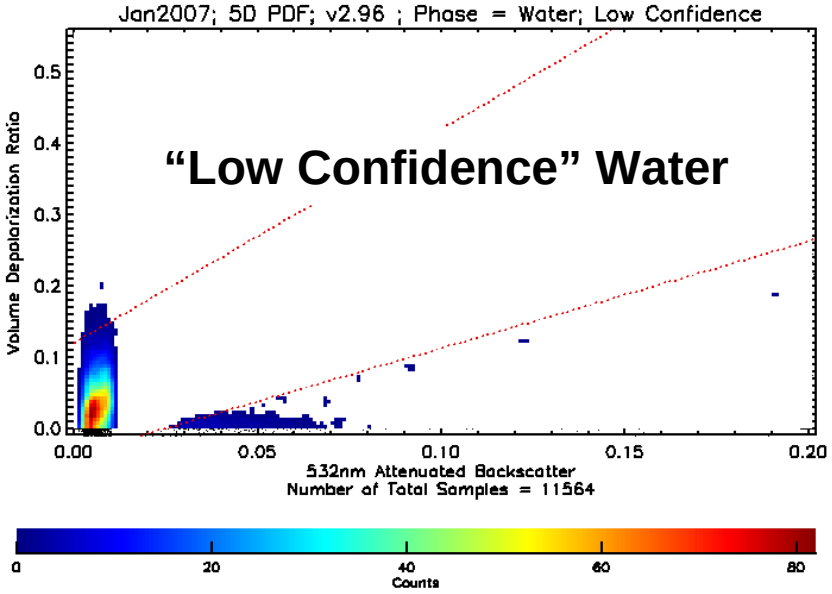
S = lidar ratio β = backscatter coefficient
R = scattering ratio $\sigma^2(x)$ = variance of x
T = transmittance τ = optical depth
m = molecular p = particulate (e.g., aerosol)
P = measured data C = calibration constant
η = multiple scattering factor

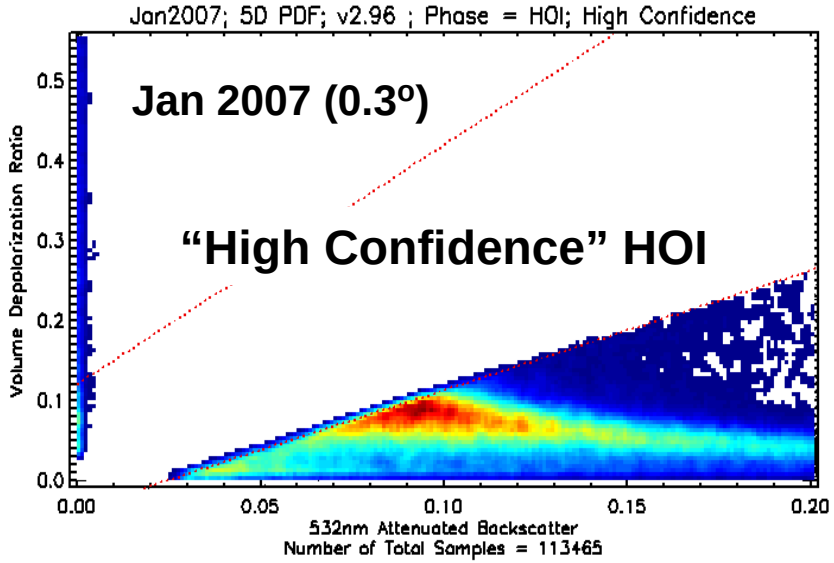
$$X_n = X(r_n) = \frac{r_n^{\ 2}\cdot P(r_n)}{C\cdot T_m^2(r_n)} \qquad A_n = \left(\frac{R_n}{R_n - 1}\right)\cdot\left(\frac{1}{1 - R_n\cdot\beta_{m,n}\cdot S\cdot\eta\cdot\Delta r_n}\right) \qquad B_n = S\cdot\eta\cdot\Delta r_n\cdot\beta_{p,n-1}$$

Version 3: New Cloud Phase Algorithm







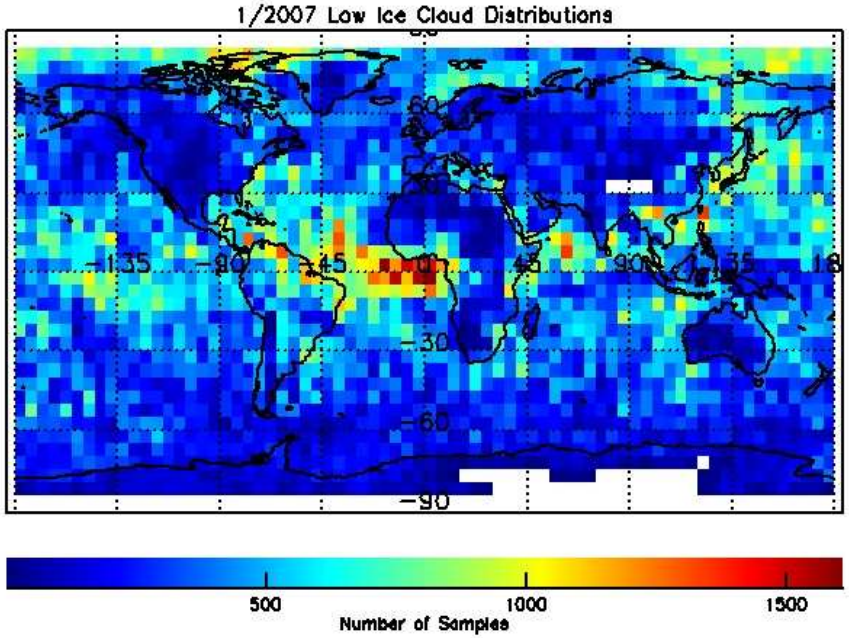


Reduced artifacts in cloud ice-water phase

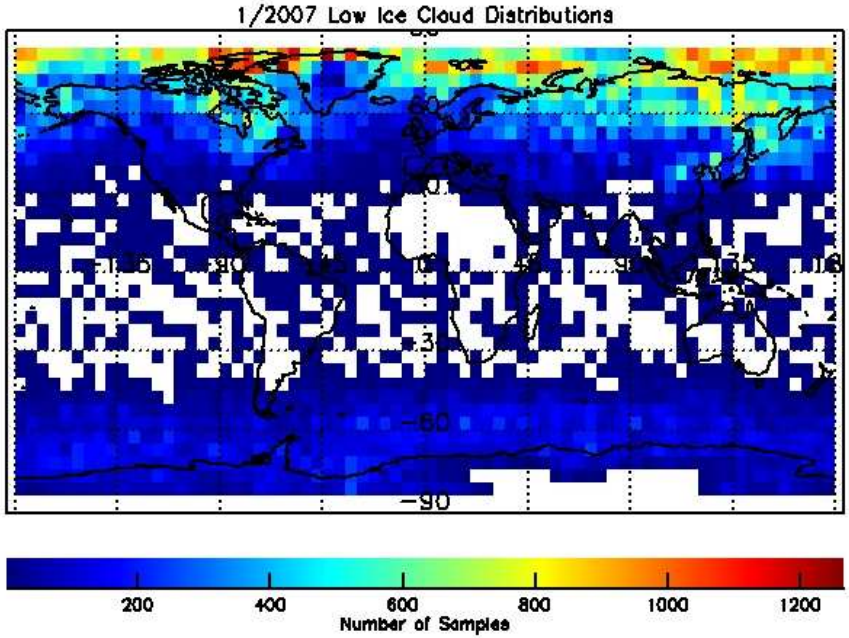
Oriented ice now properly classified (HOI → water in V2)

Improved CAD reduces mis-classification of dust as cloud

Version 2.01

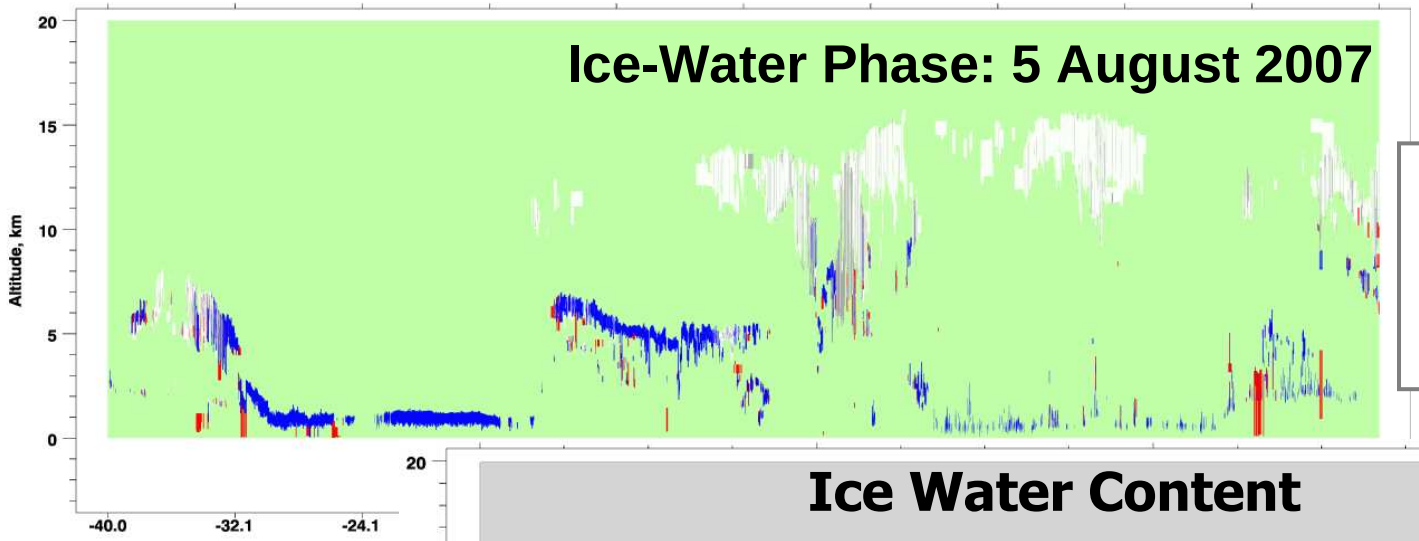


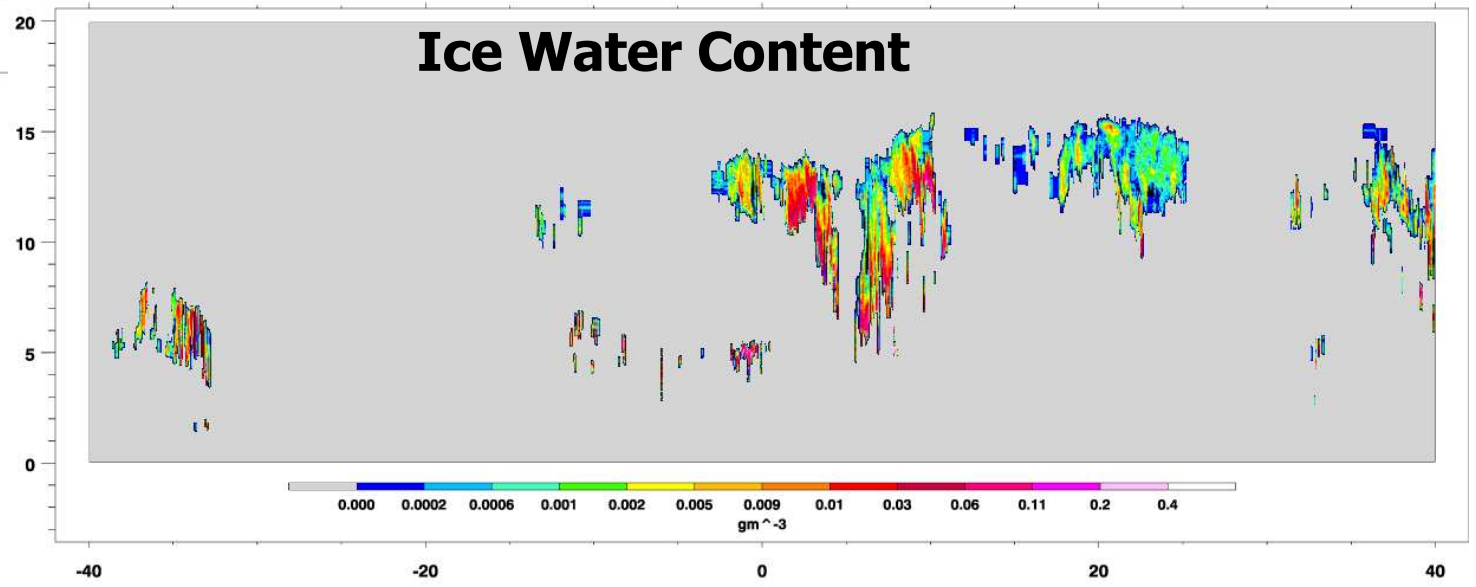
Version 3



Number of 'ice' clouds with tops below 3.25 km

New V3 product: IWC





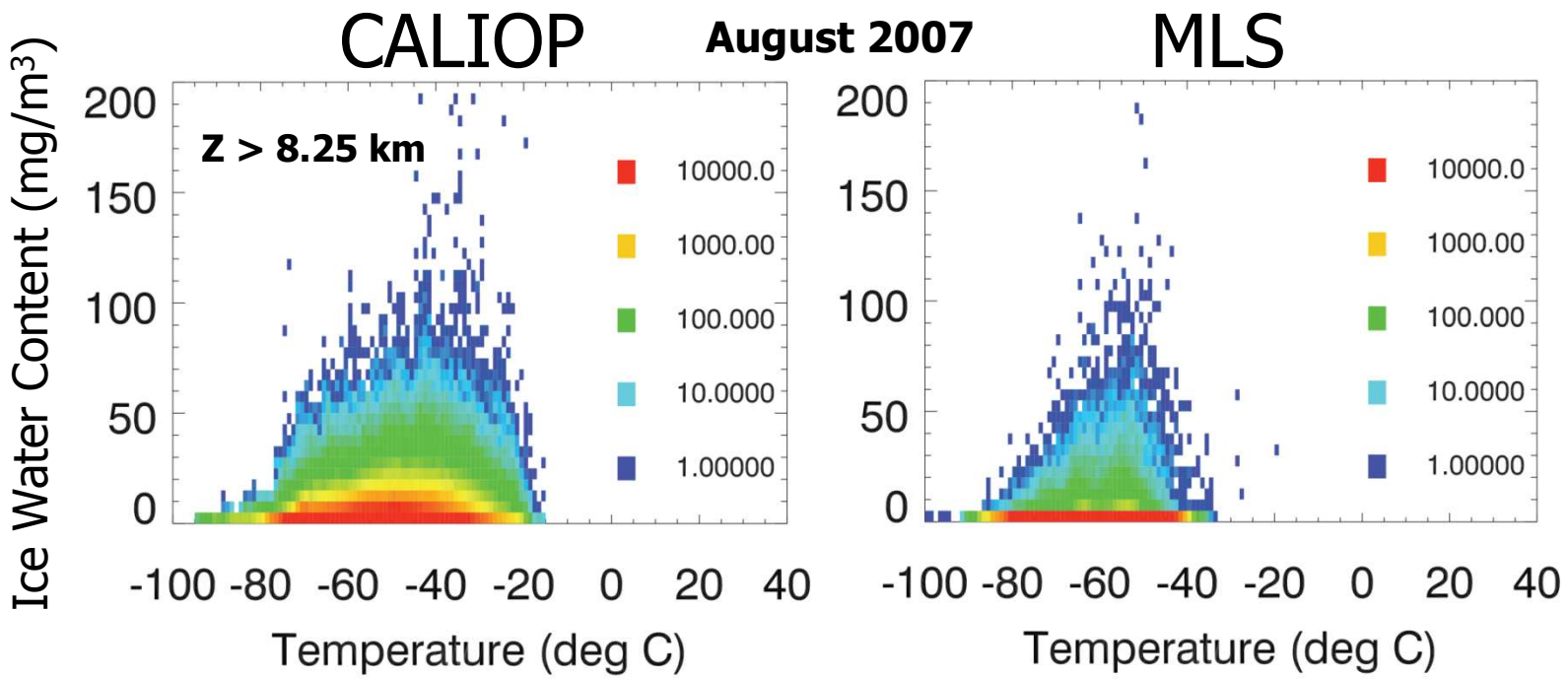
$$IWC = C_0 \left(\frac{\sigma}{1000} \right)^{C_1}$$

$C_0 = 119\ g/m^3$

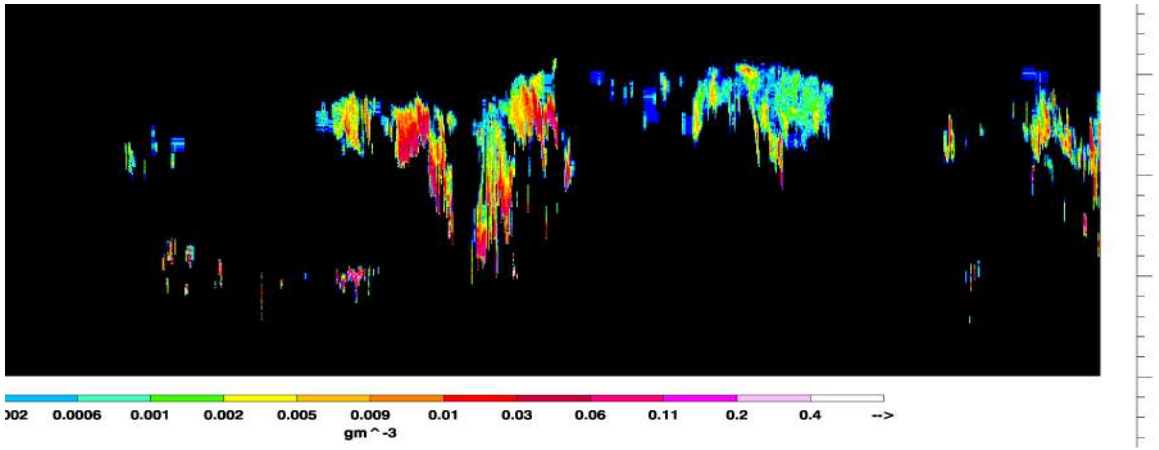
$C_1 = 1.22$

IWC parameterization from Heymsfield et al (2005)

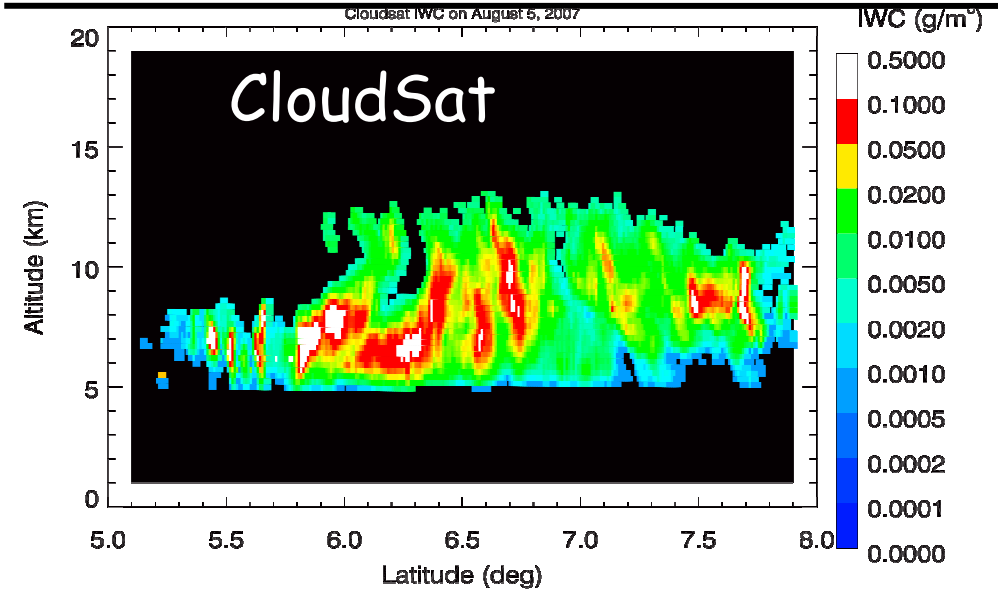
IWC Comparison

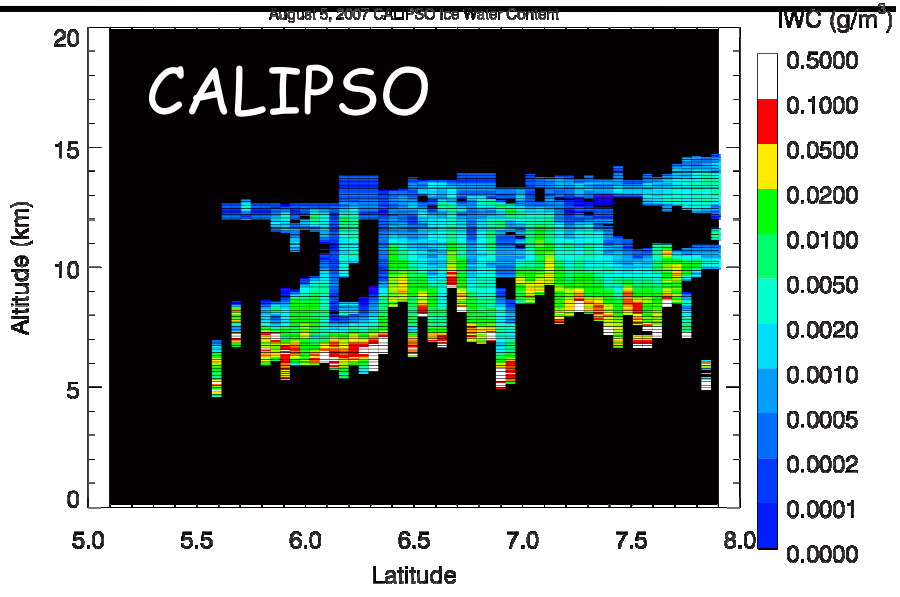


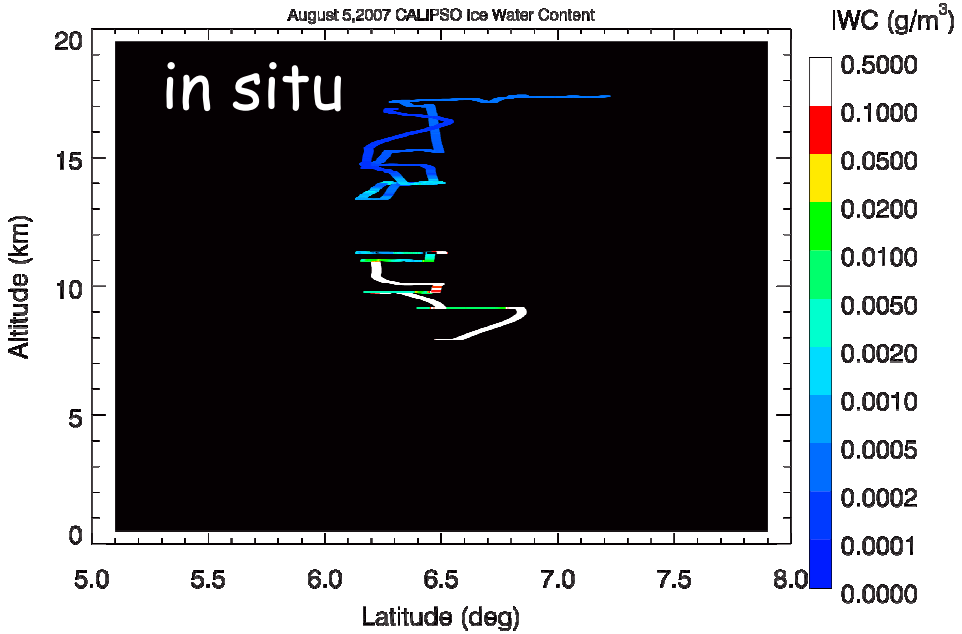
CALIOP V3.01 Cloud Ice:



Preliminary Comparison: TC4







IWC: CALIPSO vs. CloudSat

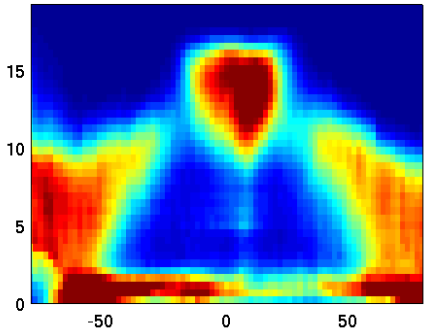
– CALIOP doesn't capture the higher IWC

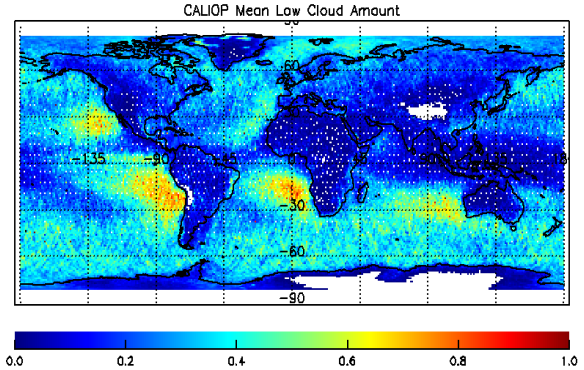
– CALIOP retrieves thin cloud ice between 10-15 km, comparable to in situ

– CloudSat IWC appears to be overestimated

Products in development

- **Level 3 Cloud product**
  - **Based on Version 3 Level 2**
  - **Builds on experience from products recently developed (using Version 2) for CMIP5/GOCCP comparison and GEWEX Cloud Assessment**

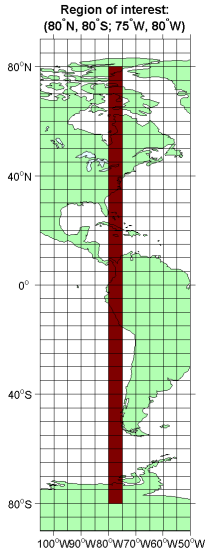


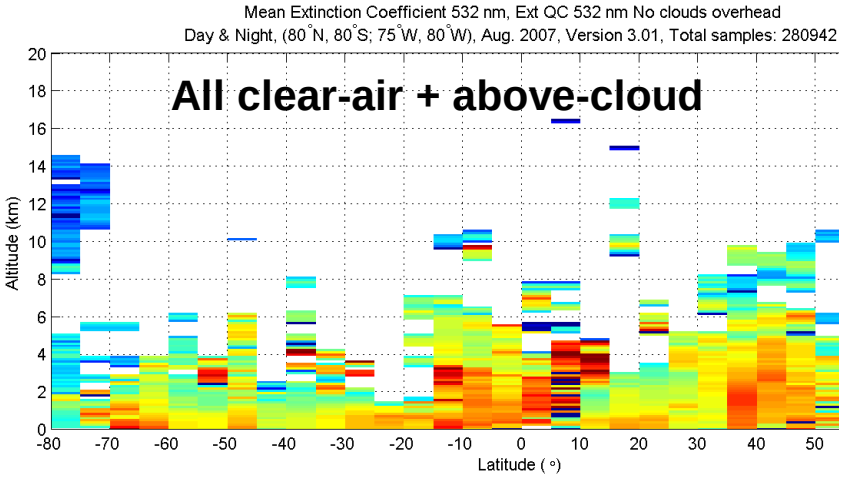


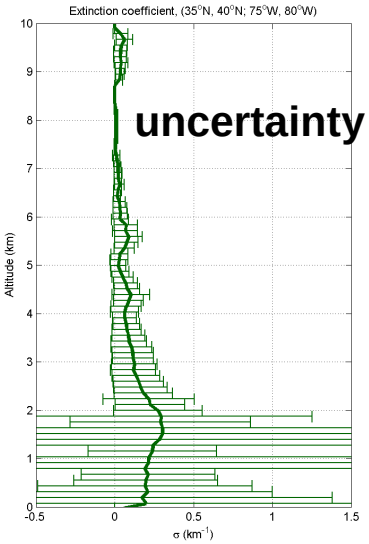
- **Level 3 aerosol product**
  - **Primarily: time-averaged gridded profiles of aerosol extinction, type**
  - **Based on Version 3 Level 2, with additional quality control**

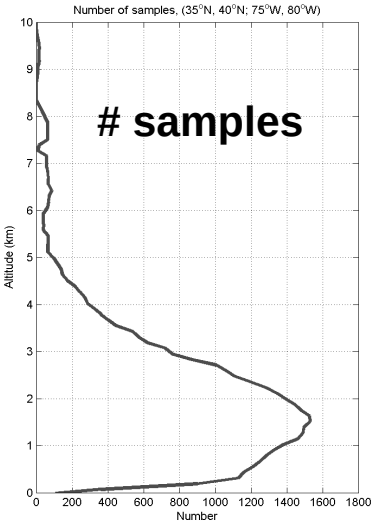
- **Near-realtime Level 1-like aerosol product for operational forecast centers**

Level 3 Aerosol Extinction - preliminary

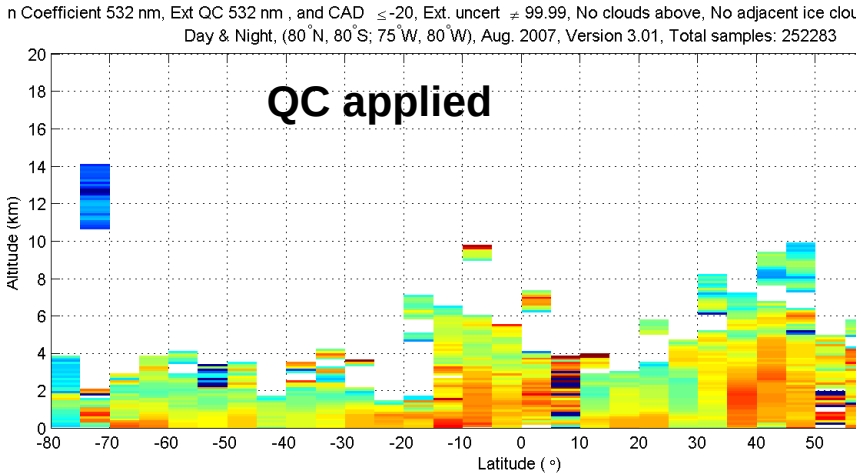


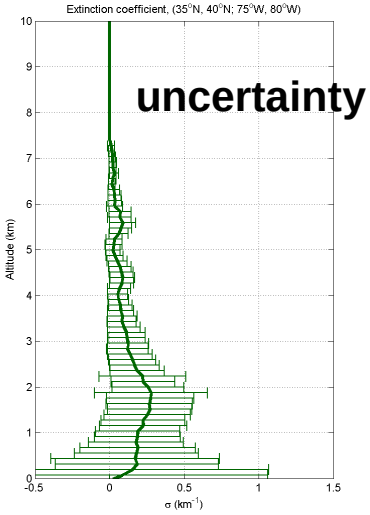


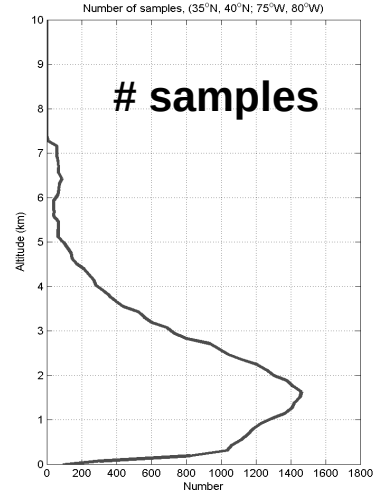




Screening: ExtUnc, ExtQC, CADscore, cloud artifacts







NRT aerosol product

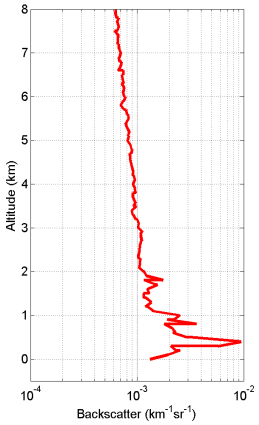
Aerosol product for model verification/assimilation by operational centers

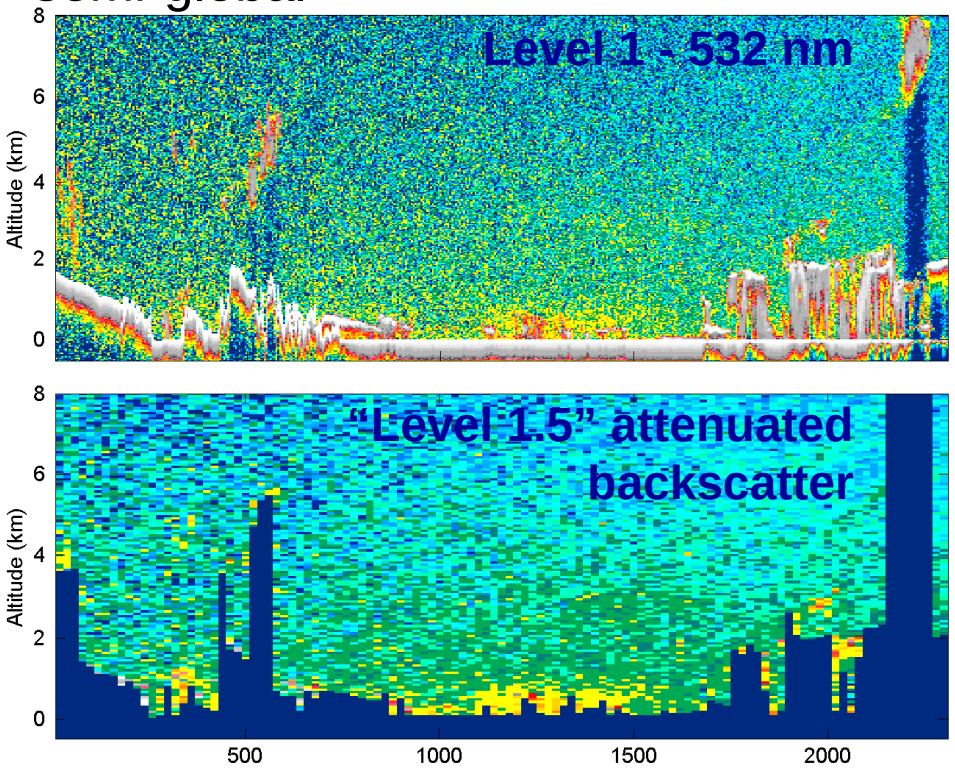
- ECMWF, NRL, GMAO, …

Level 1 profiles (1/3 km x 30-60 m) are cloud-cleared using VFM, then averaged to 20 km x 60 m

Nominal delivery within 5-6 hours → “semi-global”

Operational in early 2011





Summary

- **Have now acquired 4+ years of data**
  - **Validation continuing**
  - **Level 3 products in development**
- **Version 3 products recently released**
  - **new parameters**
  - **significant improvements over Version 2**
  - **New Level 2 IIR product by end of 2010: D_{eff} and IWC from lidar+IR**
  - **Further improvements to AOD and aerosol extinction underway**
- **Payload still healthy**
  - **Likely mission life: 2014-16**
- **Continuity of cloud/aerosol profiling:**
  - **ADM (ESA): 2011 (??)**
  - **EarthCare (ESA/JAXA): 2014**
  - **ACE (NASA): post-2020 (??)**